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**UTILITY  
PATENT APPLICATION  
TRANSMITTAL**

(Only for new nonprovisional applications under 37 CFR 1.53(b))

Attorney Docket No.

284867-00005

First Inventor

Sakhrat K. Khizroev

Title

Perpendicular Recording Head With  
Trackwidth Defined by Plating Thickness

Express Mail Label No.

EK871378804US

**APPLICATION ELEMENTS**

See MPEP chapter 600 concerning utility patent application contents.

1. ☒ Fee Transmittal Form (e.g., PTO/SB/17)  
(Submit an original and a duplicate for fee processing)
2. ☐ Applicant claims small entity status.  
See 37 CFR 1.27.
3. ☒ Specification [Total Pages ☐ 18 ]  
(preferred arrangement set forth below)
- Descriptive title of the invention
  - Cross Reference to Related Applications
  - Statement Regarding Fed sponsored R & D
  - Reference to sequence listing, a table, or a computer program listing appendix
  - Background of the Invention
  - Brief Summary of the Invention
  - Brief Description of the Drawings (if filed)
  - Detailed Description
  - Claim(s)
  - Abstract of the Disclosure
4. ☒ Drawing(s) (35 U.S.C. 113) [ Total Sheets ☐ 7 ]
5. Oath or Declaration [ Total Pages ☐ ]
- a. ☐ Newly executed (original or copy)
- b. ☐ Copy from a prior application (37 CFR 1.63 (d))  
(for continuation/divisional with Box 17 completed)
- i. ☐ **DELETION OF INVENTOR(S)**  
Signed statement attached deleting inventor(s)  
named in the prior application, see 37 CFR  
1.63(d)(2) and 1.33(b).
6. ☐ Application Data Sheet. See 37 CFR 1.76

**ADDRESS TO:**Assistant Commissioner for Patents  
Box Patent Application  
Washington, DC 20231**ACCOMPANYING APPLICATION PARTS**

9. ☐ Assignment Papers (cover sheet & document(s))
10. ☐ 37 CFR 3.73(b) Statement (when there is an assignee) ☐ Power of Attorney
11. ☐ English Translation Document (if applicable)
12. ☒ Information Disclosure Statement (IDS)/PTO-1449 ☒ Copies of IDS Citations
13. ☐ Preliminary Amendment
14. ☒ Return Receipt Postcard (MPEP 503)  
(Should be specifically itemized)
15. ☐ Certified Copy of Priority Document(s)  
(if foreign priority is claimed)
16. ☐ Other: .....

17. If a CONTINUING APPLICATION, check appropriate box, and supply the requisite information below and in a preliminary amendment, or in an Application Data Sheet under 37 CFR 1.76:

☐ Continuation☐ Divisional☐ Continuation-in-part (CIP)

of prior application No. \_\_\_\_\_ / \_\_\_\_\_

Prior application information.

Examiner \_\_\_\_\_

Group / Art Unit \_\_\_\_\_

For CONTINUATION OR DIVISIONAL APPS only: The entire disclosure of the prior application, from which an oath or declaration is supplied under Box 5b, is considered a part of the disclosure of the accompanying continuation or divisional application and is hereby incorporated by reference. The incorporation can only be relied upon when a portion has been inadvertently omitted from the submitted application parts.**18. CORRESPONDENCE ADDRESS**☐ Customer Number or Bar Code Label

(Insert Customer No. or Attach bar code label here)

or ☒

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Date 10/24/2000

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# FEE TRANSMITTAL for FY 2000

Patent fees are subject to annual revision.

TOTAL AMOUNT OF PAYMENT (\$ 750.00

## Complete if Known

Application Number	
Filing Date	
First Named Inventor	Sakhrat K. Khizroev
Examiner Name	
Group Art Unit	
Attorney Docket No.	284867-00005

## METHOD OF PAYMENT (check one)

1. ☒ The Commissioner is hereby authorized to charge indicated fees and credit any overpayments to:

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Deposit Account Name Eckert Seamans

☒ Charge Any Additional Fee Required Under 37 CFR 1.16 and 1.17

☐ Applicant claims small entity status. See 37 CFR 1.27

2. ☒ Payment Enclosed:

☒ Check ☐ Credit card ☐ Money Order ☐ Other

## FEE CALCULATION

### 1. BASIC FILING FEE

Large Entity Fee Code (\$)	Small Entity Fee Code (\$)	Fee Description	Fee Paid
101 690	201 345	Utility filing fee	710
106 310	206 155	Design filing fee	
107 480	207 240	Plant filing fee	
108 690	208 345	Reissue filing fee	
114 150	214 75	Provisional filing fee	

SUBTOTAL (1) (\$ 710

### 2. EXTRA CLAIM FEES

Total Claims	Extra Claims	Fee from below	Fee Paid
20	-20** = 0	0	0
3	-3** = 0	0	0
Multiple Dependent			

\*\*or number previously paid, if greater, For Reissues, see below

Large Entity Fee Code (\$)	Small Entity Fee Code (\$)	Fee Description
103 18	203 9	Claims in excess of 20
102 78	202 39	Independent claims in excess of 3
104 260	204 130	Multiple dependent claim, if not paid
109 78	209 39	** Reissue independent claims over original patent
110 18	210 9	** Reissue claims in excess of 20 and over original patent

SUBTOTAL (2) (\$ 0

## FEE CALCULATION (continued)

### 3. ADDITIONAL FEES

Large Entity Fee Code (\$)	Small Entity Fee Code (\$)	Fee Description	Fee Paid
105 130	205 65	Surcharge - late filing fee or oath	
127 50	227 25	Surcharge - late provisional filing fee or cover sheet	
139 130	139 130	Non-English specification	
147 2,520	147 2,520	For filing a request for ex parte reexamination	
112 920*	112 920*	Requesting publication of SIR prior to Examiner action	
113 1,840*	113 1,840*	Requesting publication of SIR after Examiner action	
115 110	215 55	Extension for reply within first month	
116 380	216 190	Extension for reply within second month	
117 870	217 435	Extension for reply within third month	
118 1,360	218 680	Extension for reply within fourth month	
128 1,850	228 925	Extension for reply within fifth month	
119 300	219 150	Notice of Appeal	
120 300	220 150	Filing a brief in support of an appeal	
121 260	221 130	Request for oral hearing	
138 1,510	138 1,510	Petition to institute a public use proceeding	
140 110	240 55	Petition to revive - unavoidable	
141 1,210	241 605	Petition to revive - unintentional	
142 1,210	242 605	Utility issue fee (or reissue)	
143 430	243 215	Design issue fee	
144 580	244 290	Plant issue fee	
122 130	122 130	Petitions to the Commissioner	
123 50	123 50	Petitions related to provisional applications	
126 240	126 240	Submission of Information Disclosure Stmt	
581 40	581 40	Recording each patent assignment per property (times number of properties)	
146 690	246 345	Filing a submission after final rejection (37 CFR § 1.129(a))	
149 690	249 345	For each additional invention to be examined (37 CFR § 1.129(b))	
179 690	279 345	Request for Continued Examination (RCE)	
169 900	169 900	Request for expedited examination of a design application	

Other fee (specify)

\* Reduced by Basic Filing Fee Paid

SUBTOTAL (3) (\$

## SUBMITTED BY

Name (Print/Type)	William F. Lang, IV	Registration No. (Attorney/Agent)	41,928	Telephone	412/566-2024
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**PERPENDICULAR RECORDING HEAD WITH TRACKWIDTH DEFINED  
BY PLATING THICKNESS**

**CROSS REFERENCE TO RELATED APPLICATION**

5           This application claims the benefit of U.S. Provisional Patent Application  
No. 60/161,690, filed October 26, 1999.

**BACKGROUND OF THE INVENTION**

**1.     Field of the Invention**

10           The invention is a perpendicular recording head for use with magnetic  
storage media. The perpendicular recording head has an unusually thin main pole  
for concentrating the magnetic flux over a smaller portion of the magnetic storage  
medium's surface area than current perpendicular recording heads.

**2.     Description of the Related Art**

15           Although other perpendicular recording heads have been developed, the  
present invention improves upon presently known perpendicular recording heads by  
utilizing a main pole made by plating a magnetically permeable material over a  
nonmagnetic substrate, thereby permitting an unusually thin main pole to be  
produced.

20           An example of a magnetic recording head is described in U.S. Pat. No.  
4,078,300, issued to J. P. Lazzari on March 14, 1978. This patent describes a  
method of making a magnetic recording head intended to work in conjunction with a  
track of a magnetic storage medium having a narrow width. The method involves  
removing material from the edges of the pole tip to reduce the surface area of the  
main pole's bottom surface.

25           U.S. Pat. No. 4,138,702, issued to J. G. Magnenet on Feb. 6, 1979,  
describes a head arrangement for perpendicular recording on a magnetic record  
carrier. The head arrangement has an electromagnet with a core and a magnetic  
shunt on opposite sides of the magnetic recording medium.

30           U.S. Pat. No. 4,546,398, issued to J. Toda et al. on Oct. 8, 1985, describes  
a perpendicular recording head. The perpendicular recording head includes a main

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pole made from a thin magnetic film, and a spiral coil electromagnetically coupled to the main pole.

U.S. Pat. No. 4,652,956, issued to H. Schewe on March 24, 1987, describes a recording head for perpendicular magnetization. The recording head has a pair of magnetic legs forming a ring-shaped member, and separate read and write wire coils. The read coil is located between the two magnetic legs, and the write coil is located outside one of the two magnetic legs.

U.S. Pat. No. 4,731,157, issued to J. P. Lazzari on March 15, 1988, describes a process for making a perpendicular recording head. The process includes the steps of depositing magnetic film on an insulating substrate, etching a channel in the magnetic film for containing a coil within a dielectric material, etching another channel in the dielectric layer for containing a second magnetic film, removing dielectric material to expose the lateral edge of the second magnetic film, and depositing additional dielectric material on top of the second magnetic film.

U.S. Pat. No. 4,943,882, issued to T. Wada et al. on July 24, 1990, describes a perpendicular recording head. The recording head includes a first main pole surrounded by a conductor coil, with an insulator covering the first main pole and coil. The first main pole is in contact with a magnetic substrate at its top end. A second main pole is in contact with the first main pole. This assembly is covered with a protective overcoat. A similar recording head is described in U.S. Pat. No. 5,225,953, also issued to T. Wada et al. on July 6, 1993.

U.S. Pat. No. 4,974,110, issued to M. Kanamine et al. on Nov. 27, 1990, describes a perpendicular recording head having a main magnetic pole, a spiral coil surrounding the main pole, and a pair of auxiliary magnetic poles on either side of the main pole. The magnetic flux from the resulting two magnetic leakage paths and the coil cancel each other out, thereby reducing edge noise.

U.S. Pat. No. 4,985,792, issued to M. B. Boir on Jan. 15, 1991, and assigned to the assignee of the present inventors, describes an improved spindle motor for a fixed disk drive for a computer.

U.S. Pat. No. 5,073,836, issued to H. S. Gill et al. on Dec. 17, 1991, describes a perpendicular recording head. The primary magnetic pole is separated from the auxiliary pole by a distance sufficient to increase the reluctance of the recording head, thereby minimizing erasure of data within the recording medium.

5 U.S. Pat. No. 5,241,430, issued to D. W. Janz on Aug. 31, 1993, and assigned to the assignee of the present inventors, describes a disk drive which accepts write operations during manufacture, but only accepts read operations in use. The drive's controller responds to power supply voltage levels available to the user's computer by performing only read operations, but will perform a write  
10 operation in response to a higher voltage.

U.S. Pat. No. 5,430,589, issued to M. B. Moir et al. on July 4, 1995, and assigned to the assignee of the present inventors, describes a disk drive having a vibration-absorbing insulator between the housing and the shaft for the storage disks.

15 U.S. Pat. No. 5,796,557, issued to G. N. Bagnell et al. on Aug. 18, 1998, and assigned to the assignee of the present inventors, describes a disk drive including six storage disks and fitting within a 3.5 inch, half height port.

U.S. Pat. No. 5,996,045, issued to L. Lee et al. on Nov. 30, 1999, and assigned to the assignee of the present inventors, describes a disk drive arrangement  
20 combining a master drive and a slave drive. Both drives use the same IDE bus. The host computer is able to send commands over the IDE bus in the same manner as if only one disk drive was present, and the command is then carried out by the appropriate drive.

The article, Sakhrat K. Khizroev, James A. Bain, and Mark H. Kryder,  
25 "Considerations in the design of Probe Heads for 100 Gbit/in<sup>2</sup> Recording Density," IEEE Transactions on Magnetics (Sept. 1997) pp. 2893-2895, describes work performed by two inventors of the present invention towards development of giant magnetoresistive read heads capable of reading magnetic storage media having high storage densities.

The article, Jon William Toigo, "Avoiding a Data Crunch," Scientific American (May 2000) pp. 58-74, describes several approaches to increasing the information storage density within fixed computer drives.

None of the above described patents and publications describes a  
5 perpendicular recording head for use with magnetic recording media having a main pole formed by plating a nonmagnetic substrate with a magnetic surface covering. Additionally, none of the above patents and publications describes a recording head having the advantages provided by the present invention.

### SUMMARY OF THE INVENTION

10 The present invention is a perpendicular recording head for use with magnetic recording media having an unusually thin main pole. The main pole is made by depositing a layer of magnetically permeable material on a nonmagnetic substrate, so that the deposited magnetic material forms the main pole. Although not limited to such use, a perpendicular recording head of the present invention is  
15 particularly useful for fixed (also known as hard) computer disk drives.

The perpendicular recording head includes a main pole, an opposing pole magnetically coupled through a joint to the main pole, and an electrically conductive coil surrounding or adjacent to the main pole. The bottom of the opposing pole has a surface area greatly exceeding the surface area of the main pole's bottom surface.  
20 Electrical current flowing through the coil creates a flux through the main pole. The direction of the flux may be reversed by reversing the direction of current flow through the coil.

A preferred and suggested method of making the main pole of the present invention begins by securing a nonmagnetic support to the joint, using well-known  
25 procedures, for example vacuum deposition. Next, a step topology is created between this substrate and the remainder of the recording head. This may be done by performing photolithography on one surface of the nonmagnetic support. The surface to be prepared is adjacent and perpendicular to the joint. Next, a magnetically permeable material is plated over the nonmagnetic substrate, so that  
30 the magnetically permeable plating forms the main pole. Due to the location of the

plated surface relative to the joint, the main pole is thereby magnetically coupled with the opposing pole through the joint, oriented so that the plated surface will be parallel to the recording head's direction of travel. Preferred magnetically permeable platings are magnetically soft materials, such as permalloy, Ni/Fe, and nitrides. The thickness of the plating can be made as narrow as a few hundred Angstroms by merely controlling plating time.

A typical magnetic recording medium for use in conjunction with a perpendicular recording head includes an upper layer having a plurality of magnetically permeable tracks separated by nonmagnetic transitions, and a magnetically permeable lower level. The lower level is magnetically soft relative to the tracks.

To write to the magnetic recording medium, the recording head is separated from the magnetic recording medium by a distance known as the flying height. The magnetic recording medium is moved past the recording head so that the recording head follows the tracks of the magnetic recording medium, with the magnetic recording medium first passing under the opposing pole and then passing under the main pole. Current is passed through the coil to create magnetic flux within the main pole. The magnetic flux will pass from the main pole through the track, into the lower layer, and across to the opposing pole. The flux will thereby cause the magnetic fields in the tracks to align with the magnetic flux of the recording head. Changing the direction of electric current changes the direction of the flux created by the recording head and therefore the magnetic fields within the magnetic recording medium. Because the surface area of the opposing pole is significantly greater than the surface area of the main pole, only the main pole will have a sufficient concentration of magnetic flux to influence the magnetic fields in the magnetic recording medium.

Reading from the magnetic recording medium may follow the opposite procedure (inductive reading). The magnetic flux of the magnetic recording medium will pass through the main pole as the main pole is passed over the recording medium. Whenever there is a change in the magnetic fields of the

recording medium, the flux within the main pole will change accordingly. Such changes in flux will induce a current within the coil.

Alternatively, a magnetoresistive or giant magnetoresistive (GMR) read head may be used with the present invention. A GMR head is made by creating a gap  
5 between the top and bottom portions of the main pole, and bridging the gap with a GMR read element. Magnetic flux flowing through the main pole will thereby be forced through the GMR read head. The magnetic flux of the magnetic recording medium will pass through the main pole as the main pole is passed over the recording medium. Whenever there is a change in the magnetic fields of the  
10 recording medium, the flux within the main pole will change accordingly. Such changes in flux will induce a current within the coil. The GMR read element will have a first electrical resistance corresponding with flux oriented in one direction, and a second electrical resistance corresponding with flux oriented in the opposing direction.

The present invention has the advantage of permitting increased information  
15 storage density within the magnetic recording medium. The density with which information may be recorded on the magnetic recording medium is limited by the effect of the recording head's magnetic flux on neighboring regions of the magnetic recording medium during read and write operations. Each discrete sector of the  
20 magnetic recording medium must be sufficiently distant from neighboring sectors so that magnetic flux from the recording head will only affect that sector which the recording head is directly over. The present invention minimizes this problem by using a head with a significantly narrower main pole than other perpendicular recording heads, thereby permitting narrower tracks to be used within the magnetic  
25 storage medium.

It is therefore an aspect of the present invention to provide a perpendicular recording head having an unusually thin main pole.

It is a further aspect of the present invention to provide a perpendicular recording head being dimensioned and configured to concentrate magnetic flux  
30 within a narrow portion of the magnetic recording medium.



It is another aspect of the present invention to provide a magnetic recording apparatus wherein information can be stored at greater densities.

It is a further aspect of the present invention to provide a method of manufacturing a perpendicular recording head adapted to permit recording on magnetic storage media at higher information densities than were available in the past.

It is another aspect of the present invention to provide a perpendicular recording head wherein the main pole is a magnetically permeable surface covering of a nonmagnetic substrate.

It is a further aspect of the present invention to provide a perpendicular recording head wherein the main pole is a magnetically permeable material plated over one surface of a nonmagnetic substrate.

These and other aspects of the invention will become more apparent through the following description and claims.

#### **BRIEF DESCRIPTION OF THE DRAWINGS**

**FIG. 1** is a top view of a typical hard disk drive for a computer for which the present invention may be used, illustrating the disk drive with its upper housing portion removed.

**FIG. 2** is a perspective, partially sectional view of a perpendicular recording head according to the present invention.

**FIG. 3** is a perspective, partially sectional view of a perpendicular GMR read head according to the present invention.

**FIG. 4** is a perspective view of an opposing pole and joint for a perpendicular recording head according to the present invention.

**FIG. 5** is a perspective view of an opposing pole and for a perpendicular recording head according to the present invention joint after addition of the substrate material.

**FIG. 6** is a perspective view of an opposing pole, joint, and substrate material for a perpendicular recording head according to the present invention after addition of photoresist.

FIG. 7 is a perspective view of an opposing pole, joint, substrate, and photoresist for a perpendicular recording head according to the present invention after removal of excess substrate material.

5 FIG. 8 is a perspective view of an opposing pole, joint, substrate, and photoresist for a perpendicular recording head according to the present invention after plating of the substrate with magnetically permeable material.

FIG. 9 is a perspective view of an opposing pole, joint, substrate, and photoresist for a perpendicular recording head according to the present invention after removal of excess plating.

10 FIG. 10 is a perspective view of an opposing pole, joint, substrate, and photoresist for a perpendicular recording head according to the present invention after removal of the photoresist.

Like reference numbers denote like elements throughout the drawings.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

15 The present invention is a perpendicular recording head for use with magnetic recording media. The recording head includes an unusually narrow main pole, made by a plating process. Perpendicular recording head main poles typically have thickness measured in a direction parallel to the tracks of the magnetic recording media, and a width defined perpendicular to the tracks of the magnetic recording medium. Platings typically have a thickness measured from the surface of the substrate to the surface of the plating. Therefore, the width of the main pole corresponds to the thickness of the plating. As used herein, recording head means a head adapted for read and/or write operations.

25 The invention will most commonly be used within a fixed disk drive 10 for computers, one of which is illustrated in FIG. 1. The fixed disk drive 10 includes a housing 12 (with the upper portion removed and the lower portion visible in this view for maximum clarity) dimensioned and configured to contain and locate the various components of the disk drive 10. The disk drive 10 includes a spindle motor 14 for rotating at least one magnetic storage medium 16 within the housing, 30 in this case a magnetic disk. At least one arm 18 is contained within the housing

12, with each arm 18 having a first end 20 with a perpendicular recording head 22, and a second end 24 pivotally mounted to a bearing 26. An actuator motor 28, such as a movable coil DC motor, is located at the arm's second end 24, pivoting the arm 18 to position the head 22 over a desired sector of the disk 16. The actuator motor 28 is regulated by a controller which is not shown, and which is well known.

The features of a perpendicular recording head 22 and corresponding magnetic storage disk 16 are best illustrated in FIG. 2. The perpendicular recording head 22 includes means for concentrating magnetic flux onto a small surface area of a magnetic recording medium, here a magnetically permeable main pole 30, oriented substantially perpendicular to the magnetic recording medium 16, and having a tip 32. The main pole 30 of the present invention is a magnetically permeable surface covering formed on surface 34 of nonmagnetic substrate 36, with the main pole 30 having a width  $W$  and thickness  $T$ . The substrate 36 is secured to a magnetically permeable joint 40, and is dimensioned and configured so that the surface 34 forms a step topology with respect to the surface 56, with a step distance  $S$  defined between the surface 56 and the main pole 30. The top 38 of the main pole 30 is thereby magnetically coupled to the joint 40. The opposite end of the joint 40 has a magnetically permeable opposing pole 42 secured to it. The opposing pole 42 includes a bottom surface 44 having a significantly larger surface area than the tip 32 of the main pole 30. With the exception of the joint 40, the main pole 30 and opposing pole 42 are separated by nonmagnetic material (not shown, but well known). An electrically conductive coil 46 is positioned adjacent to, and may surround, the main pole 30, so that the coil 46 is sufficiently close to the main pole 30 to induce a magnetic field within the main pole 30 when current passes through the coil 46. Although not shown and well understood by those skilled in the art, the coil 46 is connected to a power supply capable of supplying electrical current flowing in either direction through the coil 46, and controlled by an appropriate controller for changing the current direction as necessary to produce the desired changes in the orientation of the main pole's magnetic field.

Referring to **FIGS. 4-10**, a preferred and suggested method of making the main pole **30** begins by securing the nonmagnetic support **36** to the joint **40** (**FIGS. 4-5**). Processes for joining the nonmagnetic support **36** to the joint **40** are well known, and may include, for example, sputtering of the substrate material on the joint **40**. A preferred material for the substrate **36** is copper. The thickness **T** of the main pole **30** may be controlled by controlling the amount of substrate material deposited to form substrate **36**, and will preferably be minimized. A step topology is then created between the surface **34** of support **36** and the surface **56**, preferably by photolithography. As illustrated in **FIG. 6**, that portion of support **36** which will ultimately remain is covered by photoresist **100** before the undesirable material is etched from the substrate **36**, as in **FIG. 7**. The surface **34** has thereby been formed, and is preferably adjacent and substantially perpendicular to the joint **40**, terminating at the joint **40**. Next, a magnetically permeable material is deposited on the surface **34**, preferably by electroplating, as illustrated in **FIG. 8**, until the desired width **W** (plating thickness) is reached. The plating **102** on the top surface **104** of the substrate **36** is removed by chemical/mechanical polishing, and the photoresist **100** is removed (**FIGS. 9-10**). This magnetically permeable material now forms the main pole **30**. Because the surface **34** is adjacent to and terminates at the joint **40**, the main pole **30** abuts the joint **40**, and is thereby magnetically coupled with the joint **40**. Preferred materials for the main pole **30** are magnetically soft materials, for example, permalloy, Ni/Fe, and nitrides. The thickness of the main pole **30** may be controlled by varying the plating time.

A typical trackwidth for other magnetic recording media is approximately 1000 nm, and a main pole made by other methods generally can not be made narrower than 300 nm. By making a main pole in this manner, the main pole **30** can be made with a width **W** below 300 nm, and possibly as low as 20 nm to 30 nm. The thickness **T** of the main pole, controllable by varying the amount of substrate **36** deposited, will typically be between 100 nm to 1000 nm.

Although the plated surface described herein is surface 34, any surface of the substrate 36 perpendicular to the magnetic recording medium 16 may be plated to form the main pole 30.

Also illustrated in FIG. 2, a magnetic storage medium 16, here a magnetic disk, for use with a perpendicular recording head 22 is illustrated. The disk 16 includes an upper layer 48 having a plurality of magnetically permeable tracks 50, which are divided into sectors, with each sector having several different magnetic fields within the magnetically permeable material (not shown and well understood). The tracks 50 are separated by nonmagnetic transitions 52. The disk 16 also includes a magnetically permeable lower layer 54, which is magnetically soft relative to the tracks 50. In use, the disk 16 will be separated from the tip 32 of main pole 30 by a flying height A. The flying height A is sufficiently small so that a high concentration of flux from main pole 30 will pass through track 50, but sufficiently large to prevent damage to disk 16 from contact with recording head 22.

Recording is accomplished by rotating the disk 16 relative to the recording head 22 so that the recording head 22 is located above the appropriate sectors of the tracks 50. As recording progresses, the disk 16 will first pass under the opposing pole 42, then the main pole 30. Current will be supplied to the coil 46, thereby inducing a magnetic field within the main pole 30. The greatest concentration of flux from this magnetic field will pass from the tip 32 of the main pole 30 through the track 50 directly under the main pole 30 on which recording is being carried out, the lower layer 54, through a different track 50 directly under the opposing pole 42, continuing through the opposing pole 42 and the joint 40, and finally forming a complete loop back through the top 38 of the main pole 30. As a portion of a sector of the track 50 passes under the main pole 30, the orientation of its magnetic field will correspond to the orientation of the magnetic field of the main pole 30, which will be perpendicular to the disk 16. As the main pole 30 passes over the disk 16, the direction of current passing through the coil 46 will remain constant when a binary "0" is being recorded, thereby creating consistent orientation of the magnetic field within the track 50. The current passing through

the coil **46** will reverse directions when a binary "1" is being recorded, thereby changing the orientation of the magnetic field within the track **50**. The opposing pole **42** does not affect the magnetic fields within the upper layer **48** because the large surface area relative to the main pole **30** results in a significantly lower flux concentration through the opposing pole **42** than through the main pole **30**.

Reading from the disk **16** may be accomplished either using the same head **22**, or with a separate, identical read head adjacent to the write head **22**, or with a different style read head that may also benefit from a concave pole tip, as explained below. If the same head or another identical head is used for reading and writing, then reading is accomplished by rotating the disk **16** relative to the recording head **22** so that the desired sectors of the tracks **50** pass under the main pole **30**. As the main pole **30** passes over a magnetic field within a track **50**, the flux from the magnetic field passes through the track **50**, through the main pole **30**, joint **40**, opposing pole **42**, through another track **50**, (at a much lower flux density due to the larger surface area of opposing pole **42** relative to main pole **30**), and back through lower layer **54** to the track **50** from which reading is taking place. The main pole **30** will therefore receive a magnetic field with a flux direction corresponding to the flux direction of that portion of the track **50** directly under the main pole **30**. When the main pole **30** is passing over a region of the track **50** with a uniform flux direction, no current is induced in the coil **46**, thereby resulting in a binary "0" being read. When the main pole **30** passes over a section of the track **50** wherein the magnetic flux reverses direction, a current is induced in the coil **46**, thereby resulting in a binary "1" being read.

Alternatively, a magnetoresistive (hereinafter MR) or giant magnetoresistive (hereinafter GMR) read head **92** may be included at the first end **20** of the arm **18**, immediately adjacent to the write head **22**. GMR read heads are well known, but will be described briefly herein for purposes of illustrating the advantages of the present invention as applied to GMR read heads. A GMR read head **92** incorporating the present invention is illustrated in **FIG. 3**. The GMR read head **92** includes a magnetically permeable main pole **94**, oriented substantially

perpendicular to the magnetic recording medium **16**, and including a tip **32**. A main pole **94** of the present invention is a magnetically permeable surface covering formed on the surface **34** of the nonmagnetic substrate **36**. The substrate **34** is secured to a magnetically permeable joint **40**, and is dimensioned and configured so  
5 that the surface **34** forms a step topology with the remainder of the recording head **22**. The top **38** of the main pole **94** is thereby magnetically coupled to the joint **40**. The center **96** of the main pole **94** is split, separating the top **38** from the tip **32** with nonmagnetic material. The top **38** and tip **32** are magnetically bridged by a GMR read element **98**, so that magnetic flux will flow between the top **38** and tip **32** by  
10 passing through the GMR read element **98**. The opposite end of the joint **40** has a magnetically permeable opposing pole **42** secured to it. The opposing pole **42** includes a bottom surface **44** having a significantly larger surface area than the bottom surface **36** of the main pole **30**. With the exception of the joint **40**, the main pole **30** and opposing pole **42** are separated by nonmagnetic material (not shown,  
15 but well known). Although not shown and well understood by those skilled in the art, the head **92** is connected to and controlled by an appropriate controller for properly reading from the magnetic storage medium **16**.

As before, reading is accomplished by rotating the disk **16** relative to the read head **92** so that the desired sectors of the tracks **50** pass under the main pole  
20 **30**. As the main pole **94** passes over a magnetic field within a track **50**, the flux from the magnetic field passes through the track **50**, through the main pole **94**, joint **40**, opposing pole **42**, through another track **50**, (at a much lower flux density due to the larger surface area of opposing pole **42** relative to main pole **92**), and back through lower layer **54** to the track **50** from which reading is taking place. The  
25 main pole **94** will therefore receive a magnetic field with a flux direction corresponding to the flux direction of that portion of the track **50** directly under the main pole **30**. Because the main pole **94** is split, the magnetic flux flowing through the main pole **94** is forced through the GMR read element **98**. Changes in magnetic flux within the main pole **94** will change the electrical resistance within the GMR

read element **98**. For example, magnetic flux oriented in a first direction will produce a first level of electrical resistance within the GMR element **98**. Reversing the direction of magnetic flux will produce a second level of magnetic resistance within the GMR element **98**. A constant level of resistance will be read as a binary  
 5 “0.” Likewise, a change in resistance will be read as a binary “1.”

From the above description, it becomes apparent that, if the individual magnetic fields are too close to each other within the upper layer **48**, the process of writing to the magnetic storage medium **16** will affect not only the desired location on the disk, but also neighboring locations. Therefore, minimizing the thickness of  
 10 the main pole **30** will minimize the area of the upper layer **48** affected by magnetic flux from the main pole **30**. The tracks **50** may therefore be thinner, thereby permitting a greater number of tracks **50** within a disk, and allowing the disk to store additional information.

It is to be understood that the invention encompasses not only the preferred  
 15 embodiments described herein but also all embodiments encompassed by the following claims.



## CLAIMS

We claim:

1. A perpendicular recording head, comprising:  
a main pole; and  
5 means for concentrating magnetic flux from said main pole onto a small surface area of a magnetic recording medium.
2. A perpendicular recording head, comprising:  
a nonmagnetic substrate having a surface; and  
10 a main pole comprising a magnetically permeable plating covering said substrate's surface.
3. The perpendicular recording head according to claim 2, wherein said magnetically permeable material is an electroplated surface covering.  
15
4. The perpendicular recording head according to claim 2, wherein said nonmagnetic support defines a step topology within said recording head.
5. The perpendicular recording head according to claim 2, further comprising  
20 an electrically conductive coil adjacent to said main pole, said electrically conductive coil being electrically connected with a power supply.
6. A perpendicular recording head according to claim 2, wherein said head is a write head.  
25
7. A perpendicular recording head according to claim 2, wherein said head is a magnetoresistive read head.
8. A perpendicular recording head according to claim 2, wherein said head is a  
30 giant magnetoresistive read head.

9. The perpendicular recording head according to claim 2, wherein said main pole has a width, and said width does not exceed 300 nm.
- 5 10. The perpendicular recording head according to claim 2, wherein said main pole is made from a material selected from the group consisting of permalloy, Ni/Fe, and nitrides.
11. A method of making a main pole of a perpendicular recording head for use  
10 with a magnetic recording medium, said method comprising the steps of:  
providing a nonmagnetic substrate having a surface; and  
covering said substrate's surface with a magnetically permeable material.
12. The method according to claim 11, wherein said step of covering said  
15 substrate's surface with a magnetically permeable material is performed by plating.
13. The method according to claim 11, wherein said magnetically permeable material covering said substrate's surface is magnetically soft.
- 20 14. The method according to claim 13, wherein said magnetically permeable material covering said substrate's surface is permalloy.
15. The method according to claim 13, wherein said magnetically permeable material covering said substrate's surface is Ni/Fe.
- 25 16. The method according to claim 13, wherein said magnetically permeable material covering said substrate's surface is a nitride.

17. The method according to claim 11, further comprising the step of creating a step topology within said recording head before the step of covering said substrate's surface.

5 18. The method according to claim 17, wherein said step of creating a step topology is performed by photolithography of the nonmagnetic support in advance of depositing said magnetically permeable coating.

10 19. The method according to claim 17, further comprising the step of securing said nonmagnetic support to a joint before said step of creating a step topology within said recording head.

20. The method according to claim 19, wherein said step of securing said nonmagnetic support to a joint is performed by vacuum deposition.

15

### **ABSTRACT OF THE DISCLOSURE**

A perpendicular recording head for use with magnetic recording media includes an unusually thin main pole. The main pole is made by depositing magnetically permeable material on a nonmagnetic substrate. The main pole is then  
5 magnetically coupled with an opposing pole so that the deposited magnetically permeable material is oriented parallel to the recording head's direction of travel.

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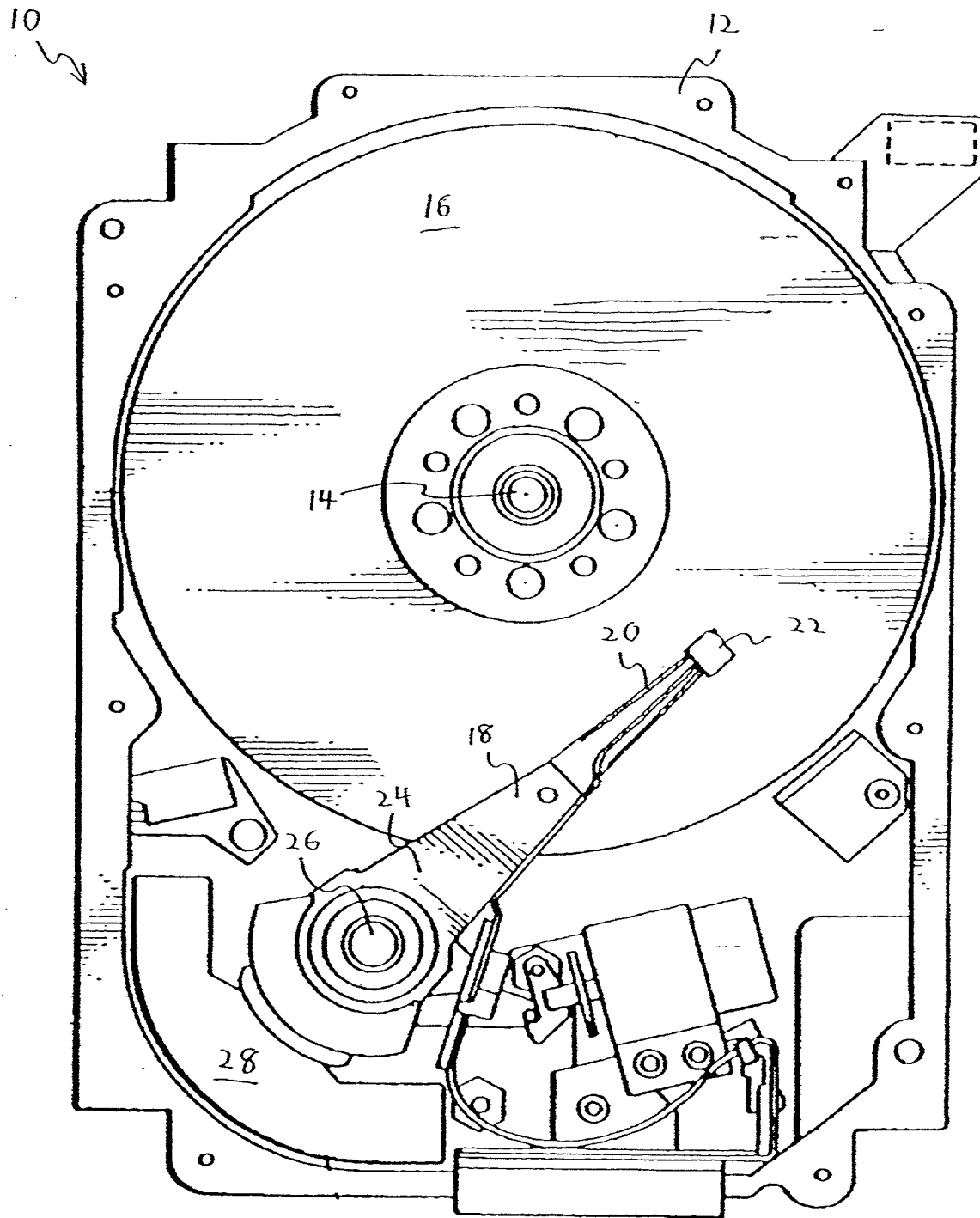


FIG. 1

FIG. 2

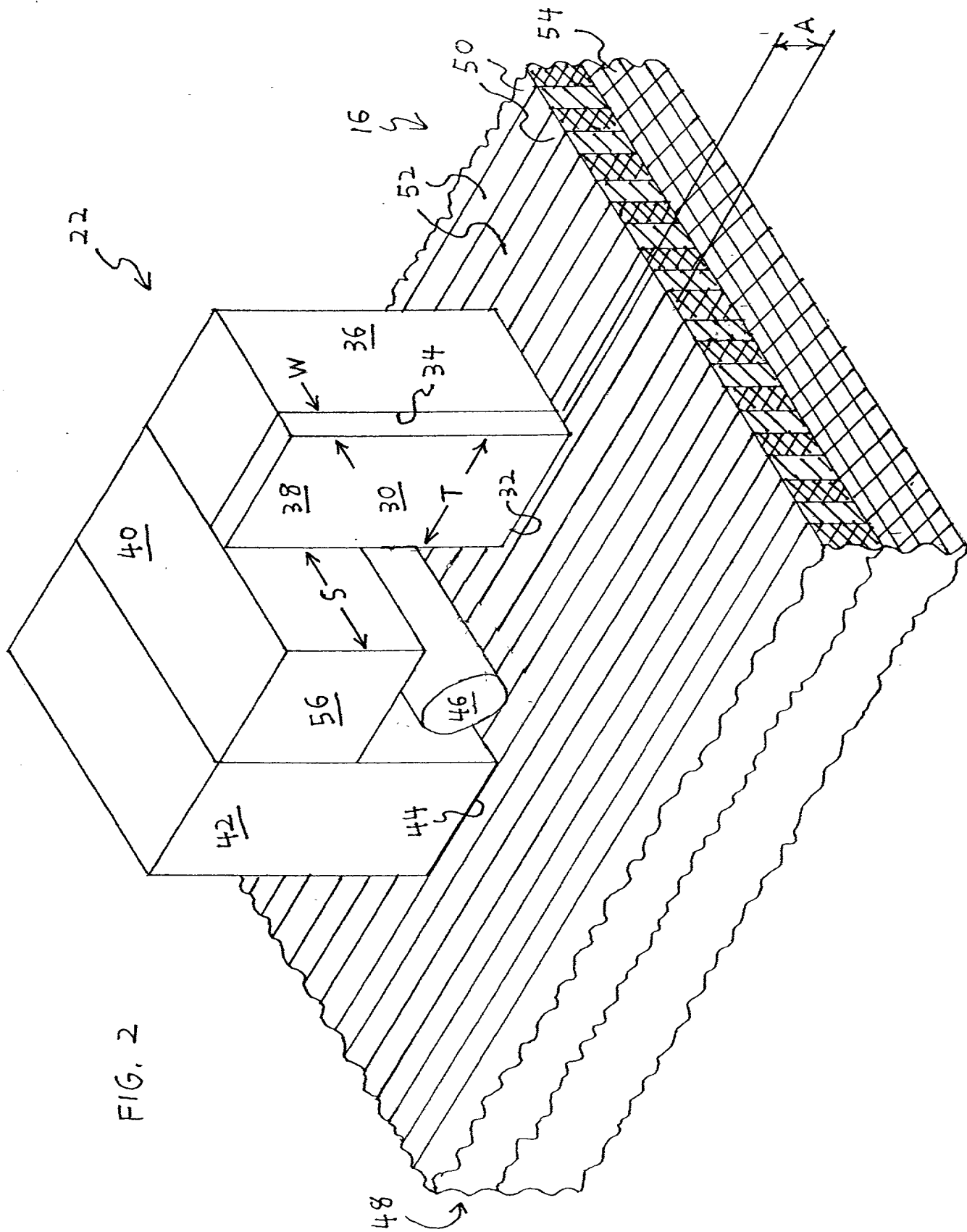


FIG. 3

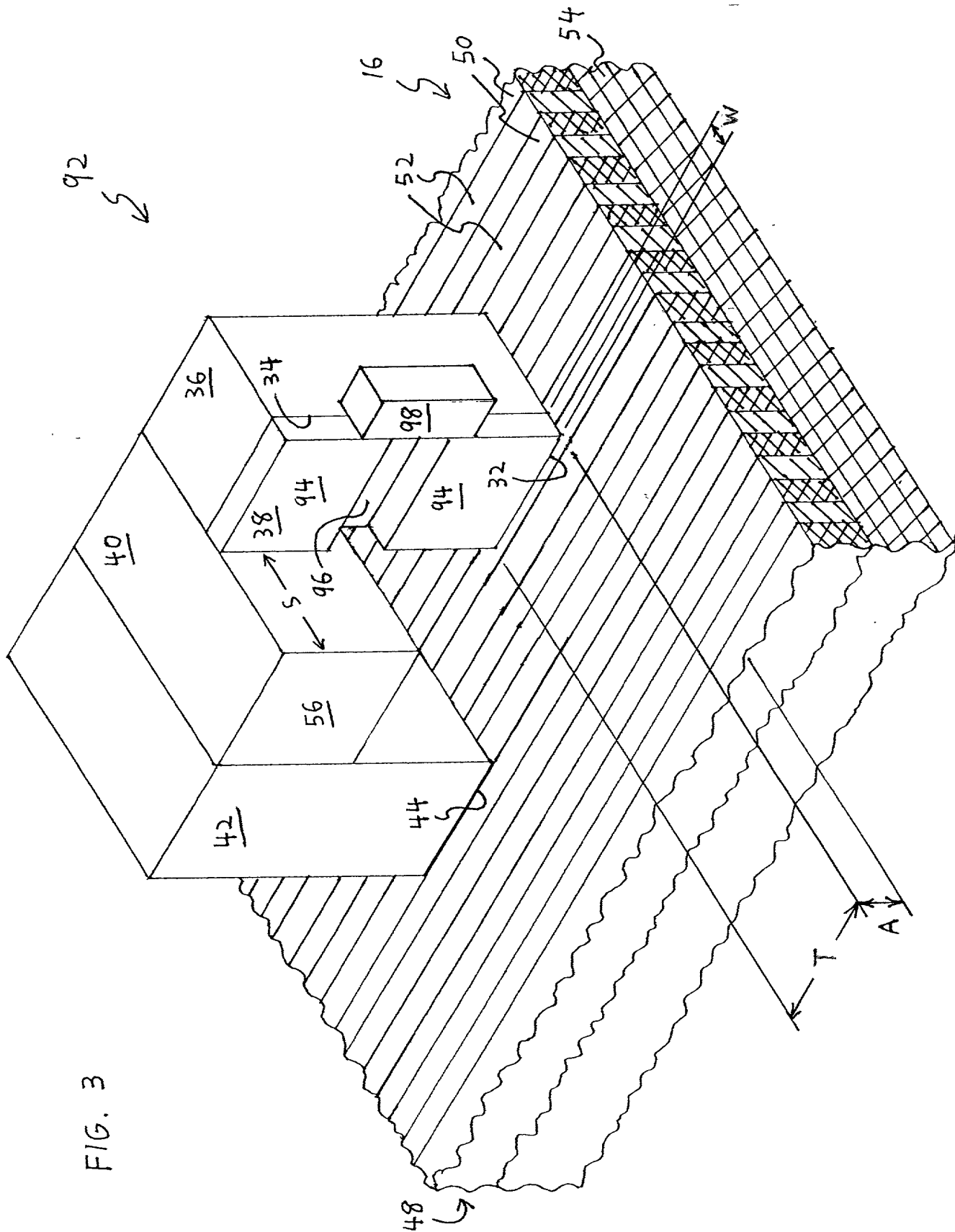


FIG. 4

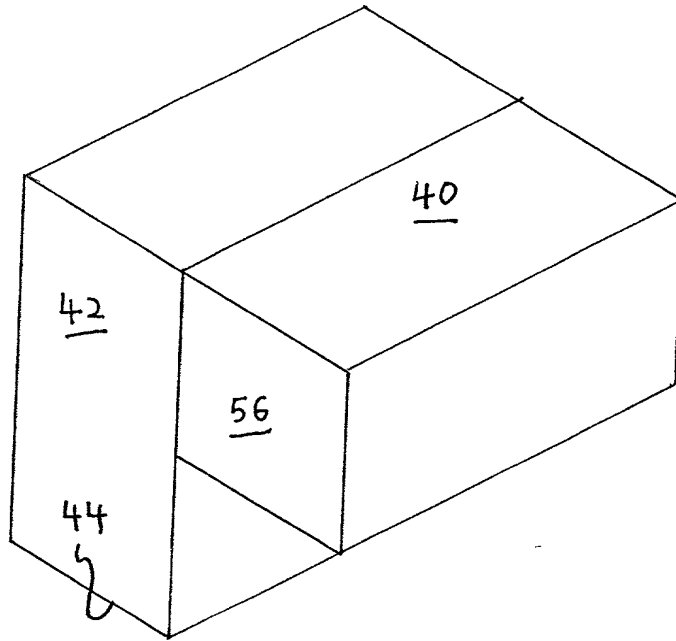


FIG. 5

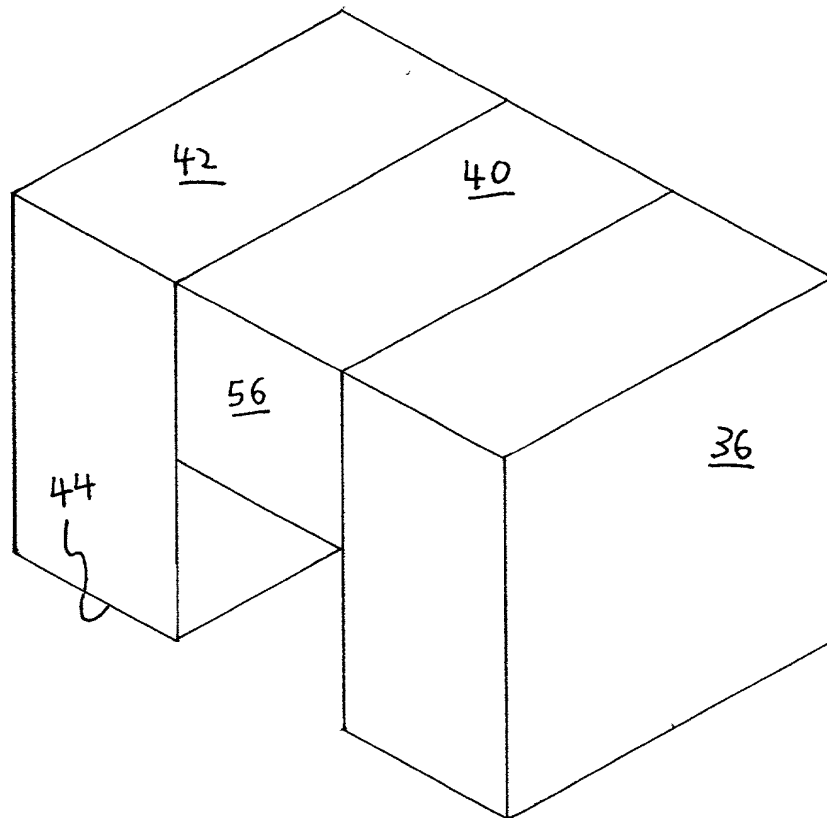




FIG. 6

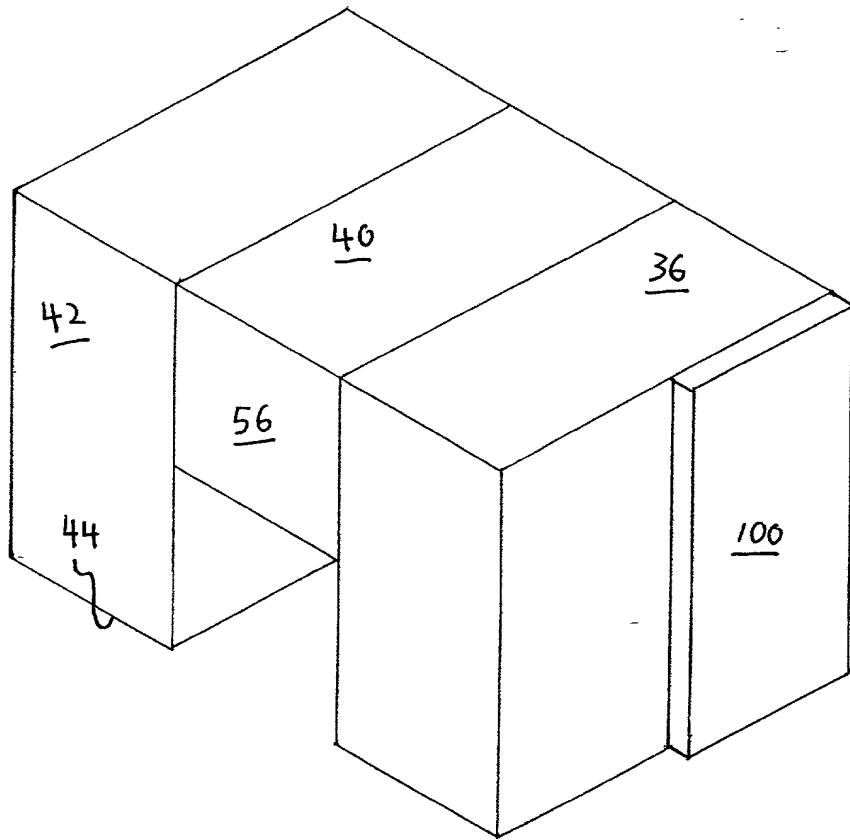
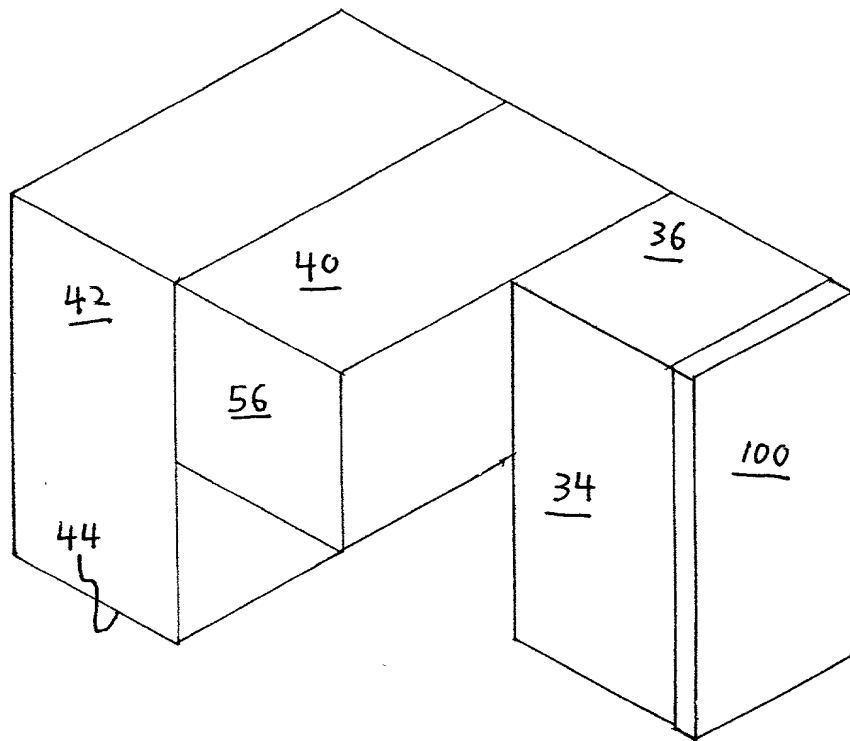


FIG. 7



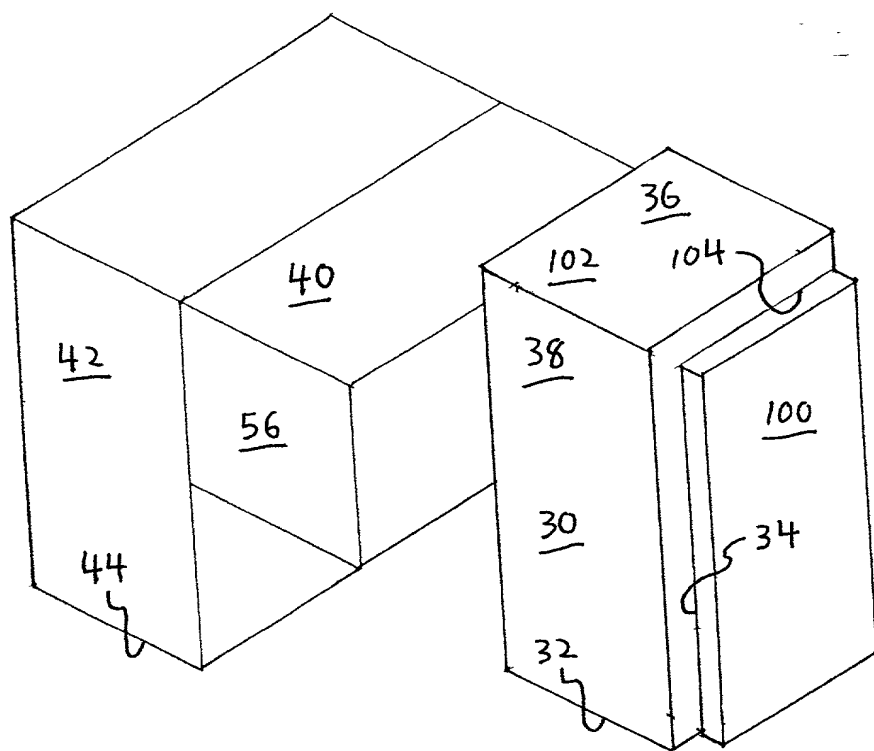


FIG. 8

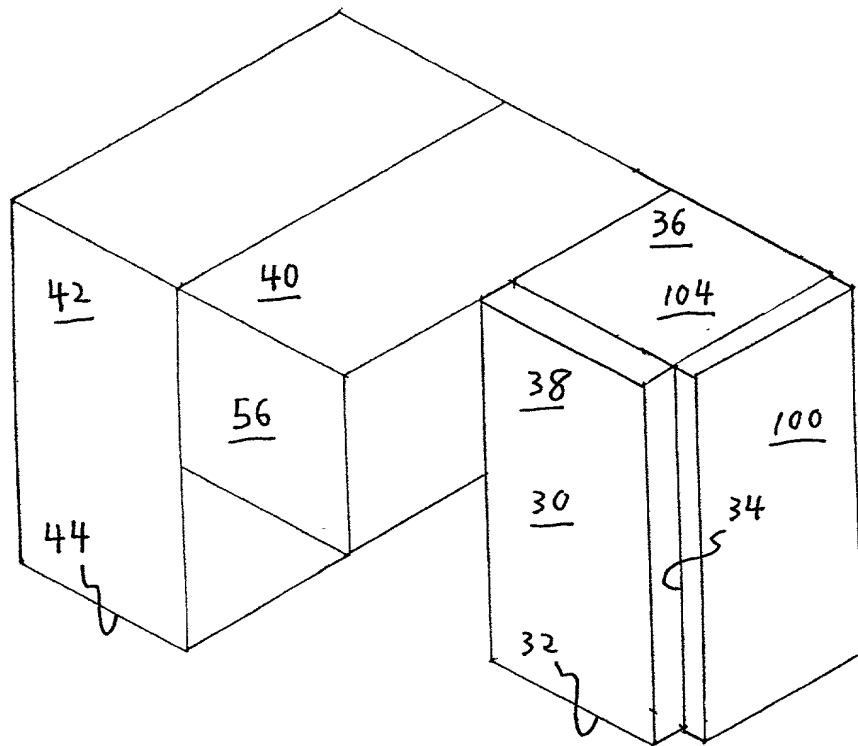


FIG. 9

Table 1. Demographic characteristics of the study population	
Age (years)	65.0 ± 1.5
Gender	
Male	50.0%
Female	50.0%
Education (years)	12.0 ± 1.0
Marital status	
Married	60.0%
Single	40.0%
Occupation	
Retired	70.0%
Unemployed	30.0%
Income (USD/month)	1,200.0 ± 200.0
Health status	
Good	80.0%
Poor	20.0%
Smoking status	
Smoker	30.0%
Non-smoker	70.0%
Alcohol consumption	
Regular	10.0%
Occasional	20.0%
Never	70.0%

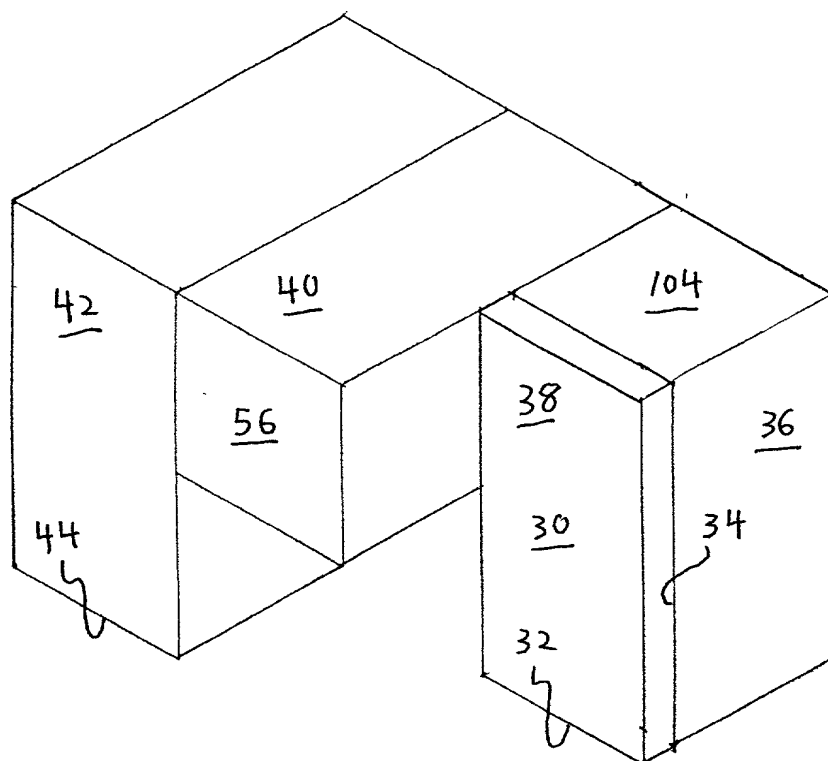


FIG. 10